Ions in LAPD

Can we Observe Them in Long Bo ?

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Goals (or Hope)

We would like so observe an effect of Argon Ion space charge in LAPD with the Long Bo TPC.

Any effect at all !

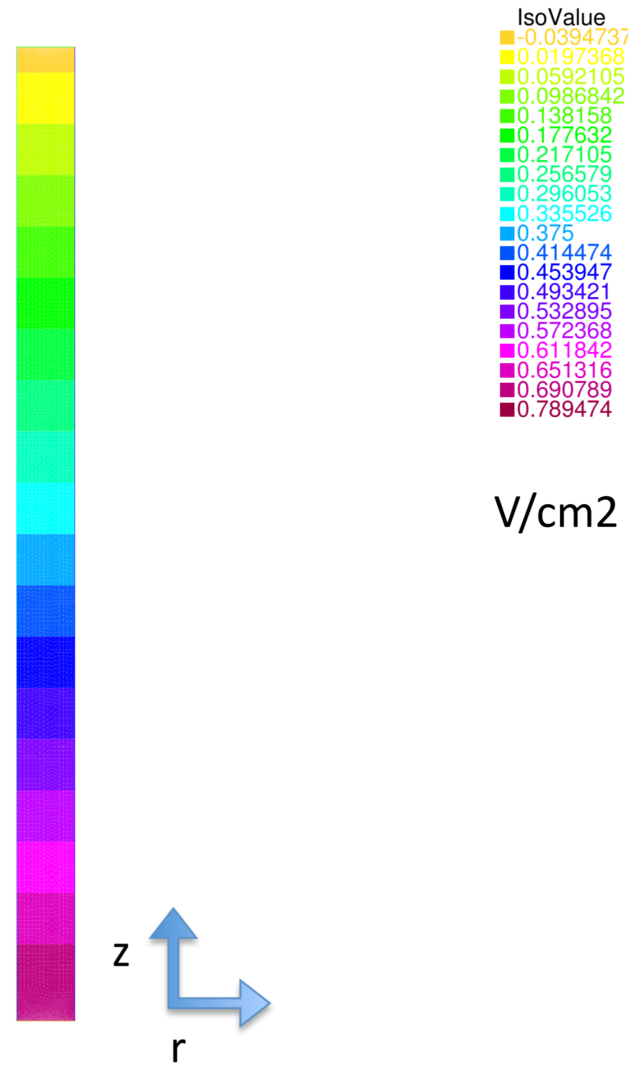
How could we observe ion space charge?

Sarah has found a free French Program to calculate the field shape from ions inside the Long Bo cylinder: FreeFem++

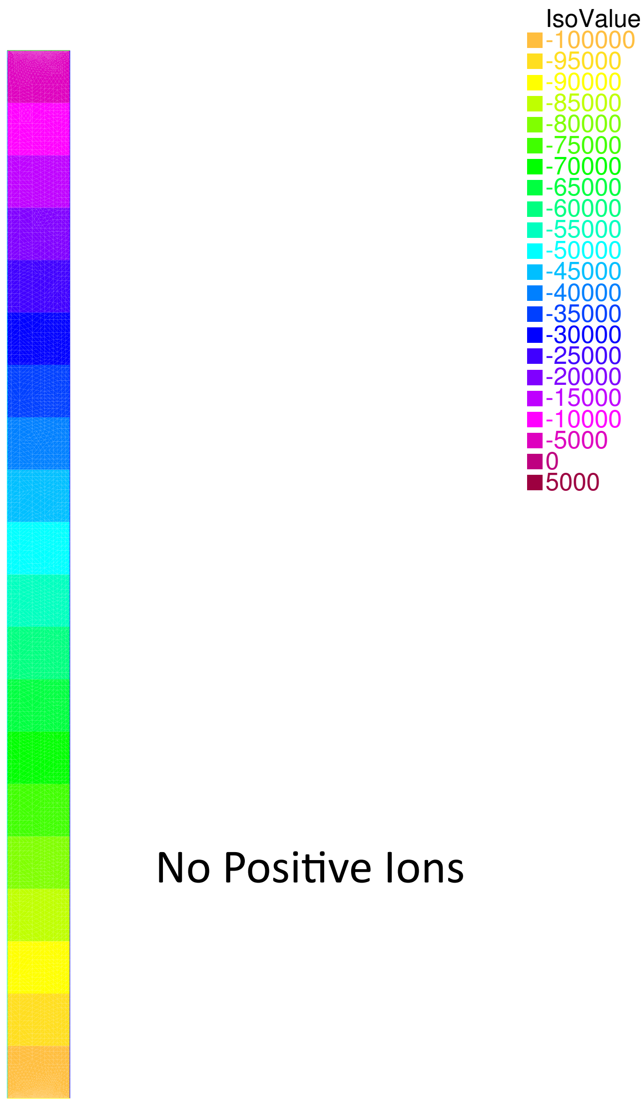
A number of assumptions were made in the calculation.

Assumptions

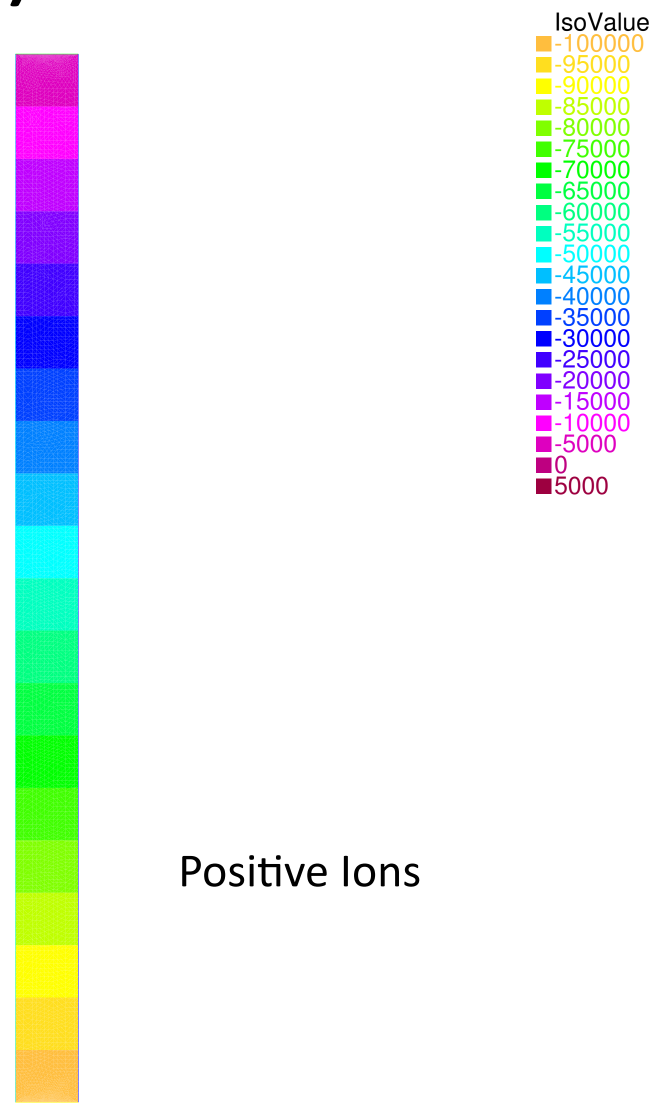
- A minimally ionizing cosmic muon produces 50 k electrons/cm
- The cosmic rate is 1/(min cm2)
- Positive ions move at a rate of 0.5 cm/s
- The relative permittivity of LAr is 1.6
- The radius of Long Bo is 12.5 cm and length is 2 m
- Charge distribution is linear in z:
- No flow!



Potential (V)

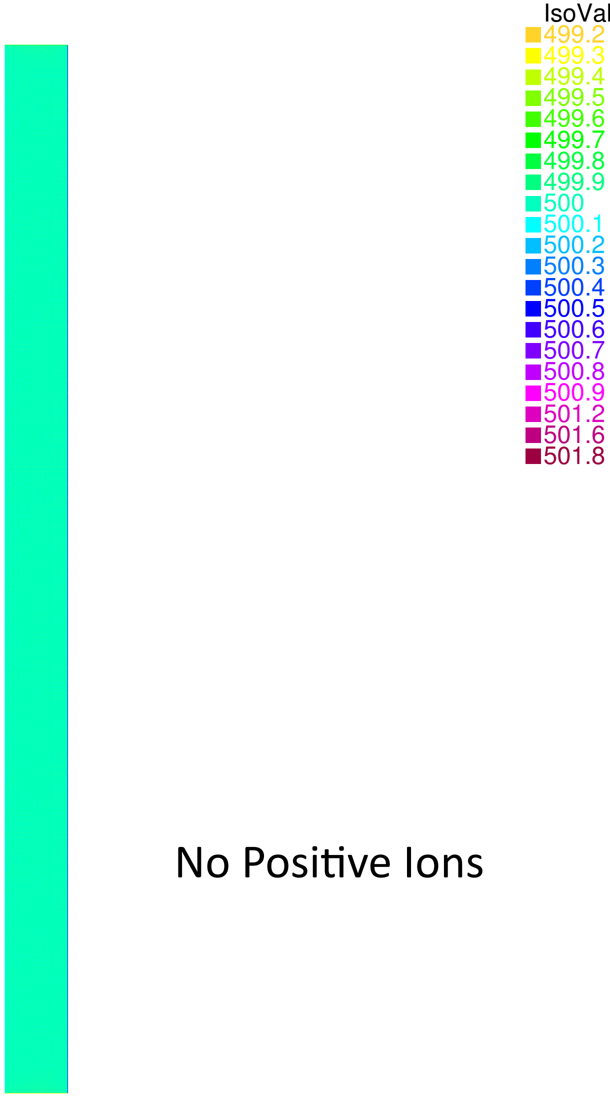


No Positive Ions

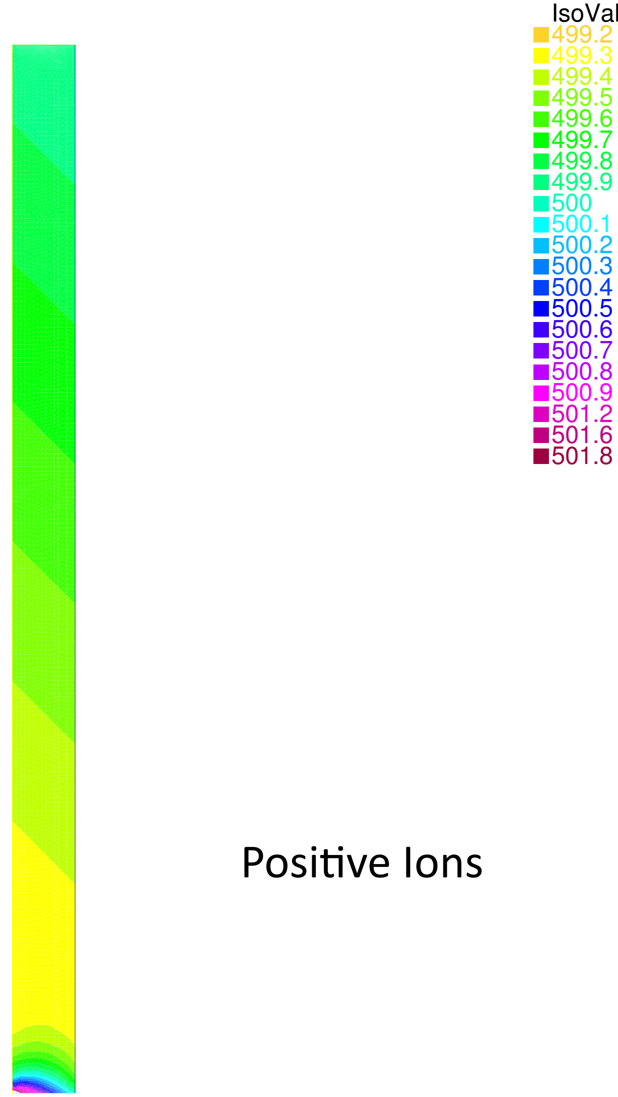


Positive Ions

E Field (V/cm)

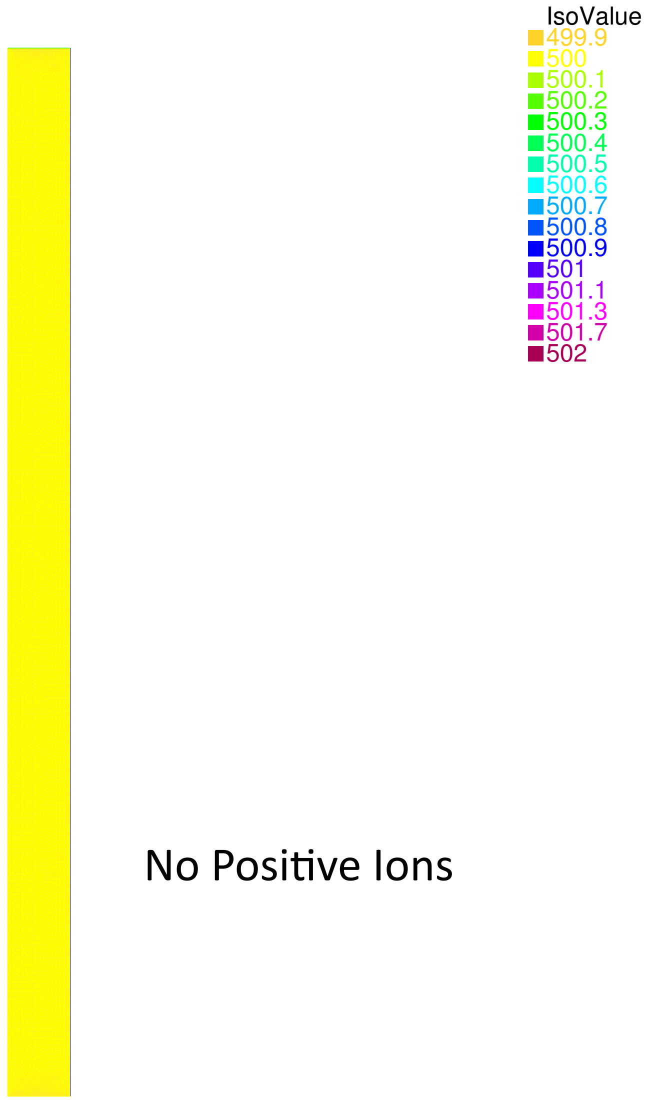


No Positive Ions

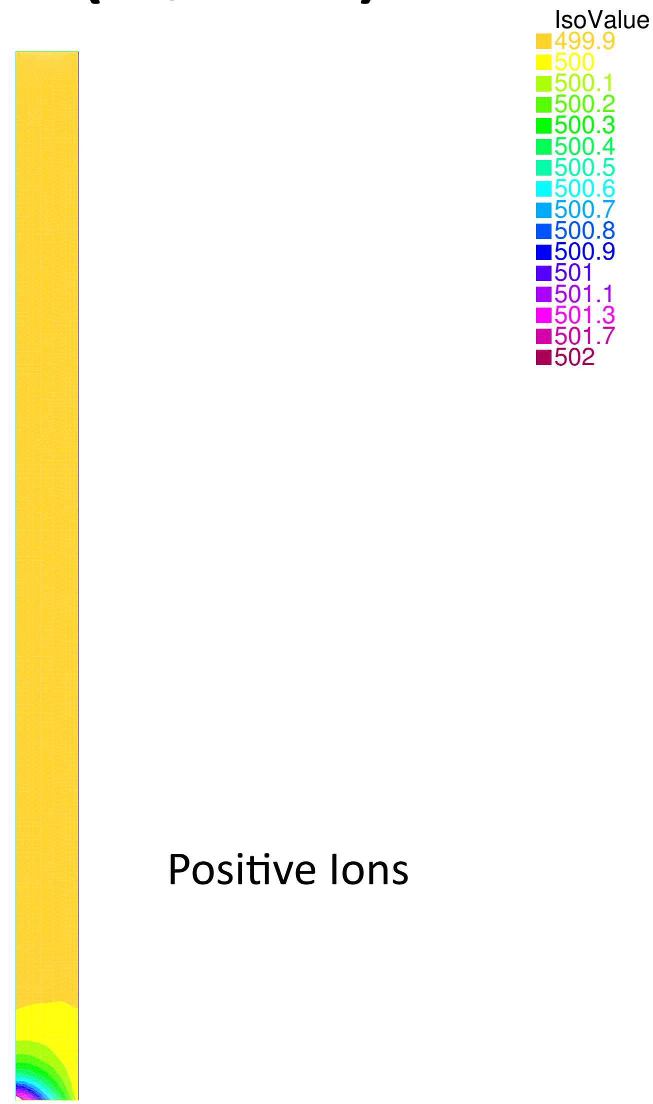


Positive Ions

E Field in Z Direction (V/cm)

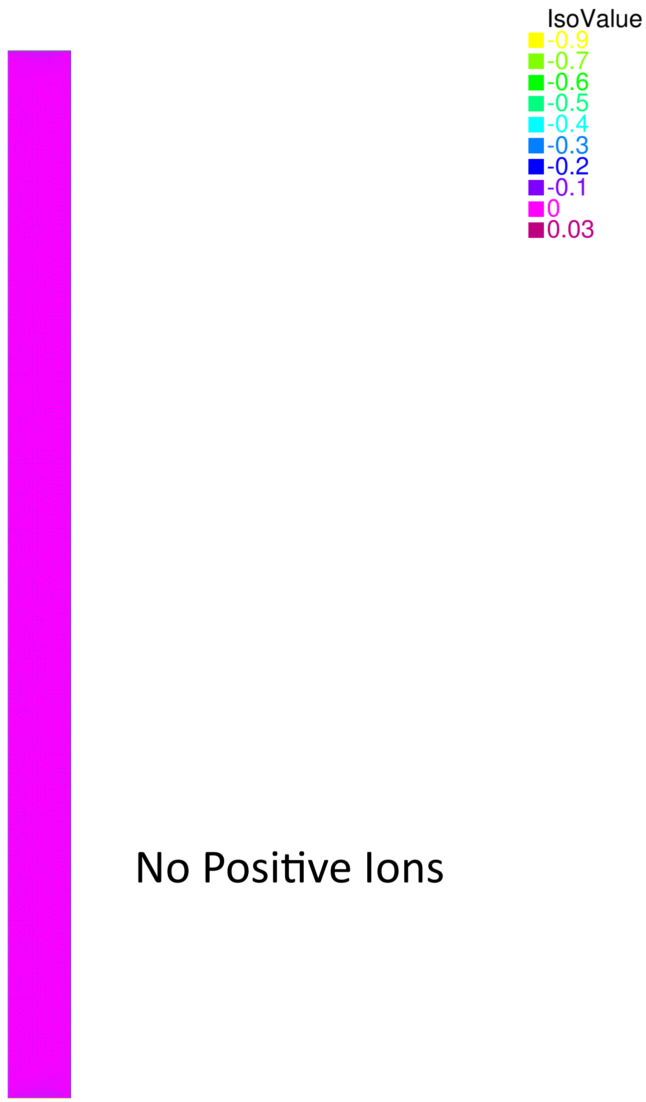


No Positive Ions

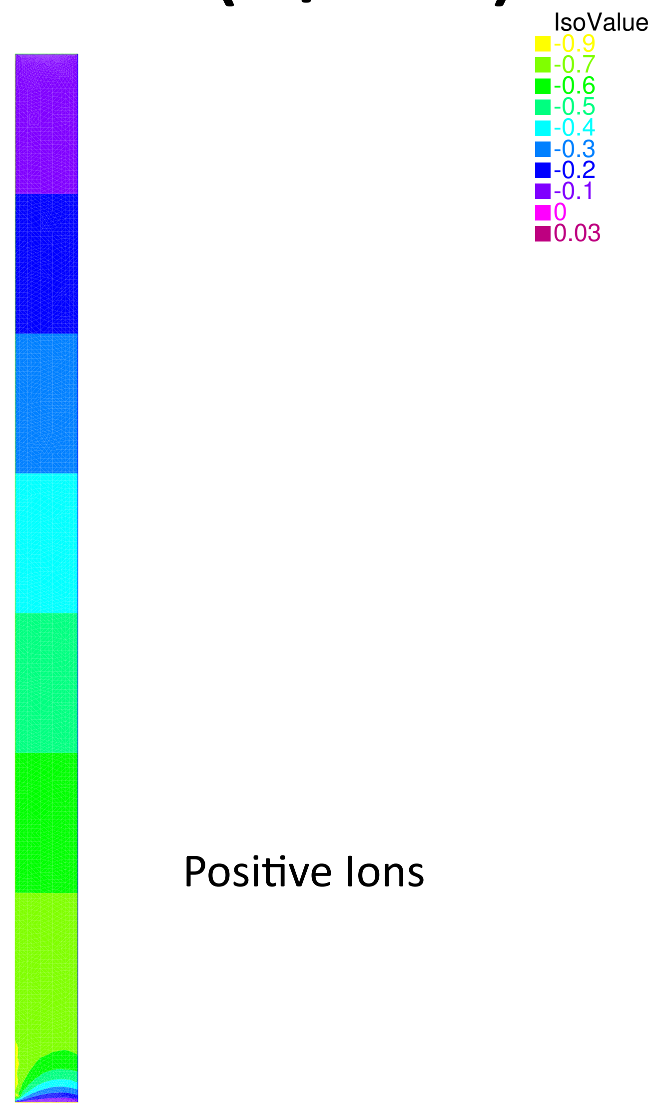


Positive Ions

E Field in Radial Direction (V/cm)



No Positive Ions



Positive Ions

What have we learned?

Sarah's calculations assumed a triangular (versus z) charge distribution.

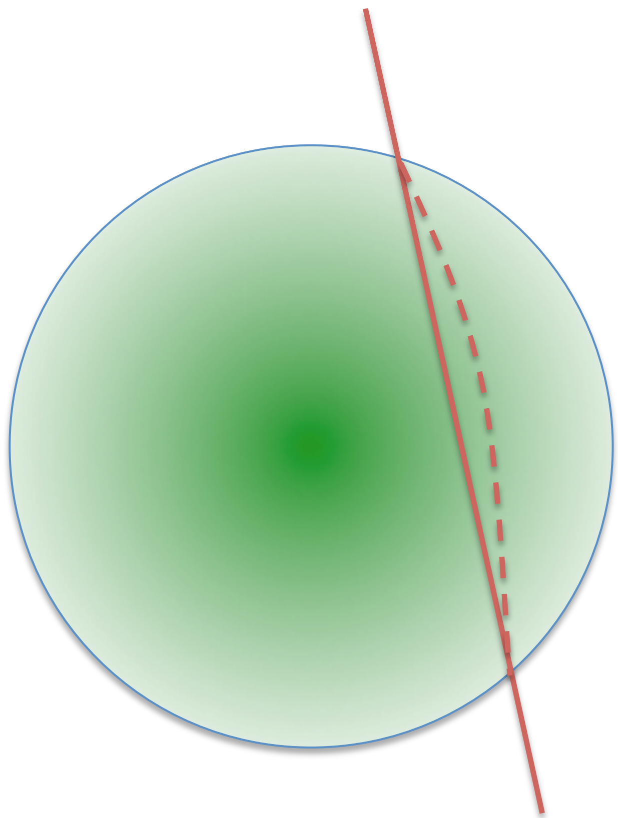
The ions from cosmics are continuously generated in the standard drift field, and continuously swept by the drift field.

We note that the calculated radial field may be detectable, but only about 0.14 % of the drift (☹)

Mode of detection

Looking for effects of the change in drift field strength is difficult.
The track location (i.e. distance from the wires) would have to be known very accurately.

Instead we can detect the radial electric field generated by the ion charge cloud.
The radial drift field will cause tracks to appear slightly bent, especially if they originate far from the anode and occur near the periphery.
This is a striking and entirely predictable effect if the charge density is known. Or, one can find the charge density from the track bending.



What is the ion density, though ?

Previous (bad) assumption:

The LAr inside the TPC is stationary, i.e. there is no flow.

What we think we know:

The ions drift at 0.5 cm/ sec, and take 400 sec to be swept to the cathode.

The Argon is expected to flow up along the tank walls (due to heat input) and flow down at the center,

roughly in a smoke ring pattern.

Calculations show a velocity of a few mm per second,

Similar to the ion drift velocity.

More about the the ion density

With the added flow motion we expect:

Both motions are down, hence the ion dwell time in the TPC is shortened to about 200 sec.

There is less time to accumulate ions.

This reduces the assumed ion density twofold.

Hence the radial field is now expected to be only 0.07% of the drift filed.

As an example,

The biggest effect is for an electron traveling the full length of the TPC (2 m)

At the biggest radius, where the radial field is the full 0.07%,

the expected track sagitta would be less than

(2 m) * (0.07%) = 1.4 mm

Looks hard!

Excellent mixing!

The dwell time for ions I the TPC is short, causing a large dilution into the LAr inventory (the TPC volume is less than 1% of the LAR volume in the tank.

Are ions generated in the tank, outside the TPC ?

Where are ions made ?

Ions can only be made in regions of significant electric field.

Why ?

A minor contributor is the reduced ion yield from immediate recombination .

The dominating effect is this:

Electrons need to be swept out of the ionization area, to a wall, within the electron life time.

If not, they attach themselves to an impurity, e.g. a water molecule, and will stop moving quickly.

The result is a neutral plasma, moving sluggishly,

but causing no net charge accumulation.

Electric field in the Tank outside the TPC

There are two aspects to this question:

a. There is a (mostly) radial electric field due to the field cage

This field is not zero, but smaller than the drift field inside the TPC.

As explained above, in order to create a net charge from positive ions, the electrons need to be swept out to a wall. The effectiveness of sweeping the electrons depends on the field distribution and , quite sensitively, on the electron lifetime.

We have no estimate of this at the moment.

And it may not matter.

b. This field may well be zero

The field cage consists of Cu electrodes on the inside of rolled G10 sheet.

The outside of the field is initially charged (capacitively) but may attract enough positive charges (Ar+ ions) to reduce the field outside the field cage. This will happen in a a day or so due to cosmic rays. (The field will not all the way go to zero because the field reduction will slow argon ion production.)

We tried to measure the resistivity of cold G10 with summer people,

But the current was too low to measure.

We obtained an upper limit of 1.8 e14 Ohm m, as described in LArTPC Doc # 894

Ion Accumulation

We have addressed (though not solved) ion generation.

What happens to the ions?

Who eats them ?

a. LAr flow and the walls

Ions will occasionally be carried near a conductor.

In order to be attracted to its mirror image, and ion needs to be quite close to the conductor, a few atomic diameters, probably.

This does not sound like an important eater of ions.

b. While being pumped through the filter system

This trip provides many opportunities for Ar ions to meet a conductor. It may be the dominant loss mechanism for ions

Ions in other experiments

Efficient LAr TPC' s will try to maximize the active volume.

MicroBooNE, e.g., has a drift field in 1/3 of the LAr, and the space outside (except for the anode region) has very high fields.

The same is true for LBNE and, to a lesser extent, of 35 ton phase II

If the present analysis is correct, Long Bo presents an exceptionally difficult system to study ion effects

Conclusions

- It would be highly desirable to study space charge effects from Argon ions experimentally
- We have identified a promising detection mode
- For ions made inside the TPC, however, the expected track sagitta is well below 1.3 mm –barely observable
- We do not expect ions to be made effectively outside the TPC

Unless this is wrong !!

Backup Slide

To compute the charge distribution, we assume a steady state is reached after 400 seconds, so

$$\begin{aligned}\langle\rho(z)\rangle &= \frac{1}{60 \text{ sec cm}^2} \cdot 400 \text{ sec} \cdot \frac{50,000 \text{ e}}{\text{cm}} \cdot \frac{1.6 \times 10^{-19} \text{ C}}{1 \text{ e}} \\ &= 5.33 \times 10^{-14} \text{ C/cm}^3\end{aligned}$$

Then, if we assume a linear charge distribution in z, we have

$$\rho(z) = 2\langle\rho(z)\rangle\left(1 - \frac{z}{L}\right)$$

Then

$$\begin{aligned}\nabla^2\phi &= \frac{\rho}{\epsilon} \\ &= \frac{2\langle\rho(z)\rangle\left(1 - \frac{z}{L}\right)}{\epsilon}\end{aligned}$$

and

$$\begin{aligned}\langle\rho(z)\rangle &= 5.33 \times 10^{-14} \frac{\text{C}}{\text{cm}^3} \\ \epsilon &= 1.42 \times 10^{-13} \frac{\text{C}}{\text{V cm}}\end{aligned}$$

so

$$\nabla^2\phi = 0.75 \cdot (1 - \frac{z}{L}) \cdot \frac{\text{V}}{\text{cm}^2}$$